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More than "100 worst" alien species in Europe

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Abstract "One hundred worst" lists of alien species of the greatest concern proved useful for raising awareness of the risks and impacts of biological invasions amongst the general public, politicians and stakeholders. All lists so far have been based on expert opinion and primarily aimed at representativeness of the taxonomic and habitat diversity rather than at quantifying the harm the alien species cause. We used the generic impact scoring system (GISS) to rank 486 alien species established in Europe from a wide range of taxonomic groups to identify those with the highest environmental and socioeconomic impact. GISS assigns 12 categories of impact, each quantified on a scale from 0 (no impact detectable) to 5 (the highest impact possible). We ranked species by their total sum of scores and by the number of the highest impact scores. We also compared the listing based on GISS with other expert-based lists of the "worst" invaders. We propose a list of 149 alien species, comprising 54 plants, 49 invertebrates, 40 vertebrates and 6 fungi. Among the highest ranking species are one bird (*Branta canadensis*), four mammals (*Rattus norvegicus, Ondatra zibethicus, Cervus nippon, Muntiacus reevesi*), one crayfish (*Procambarus clarkii*), one mite

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(*Varroa destructor*), and four plants (*Acacia dealbata, Lantana camara, Pueraria lobata, Eichhornia crassipes*). In contrast to other existing expert-based "worst" lists, the GISS-based list given here highlights some alien species with high impacts that are not represented on any other list. The GISS provides an objective and transparent method to aid prioritization of alien species for management according to their impacts, applicable across taxa and habitats. Our ranking can also be used for justifying inclusion on lists such as the alien species of Union concern of the European Commission, and to fulfil Aichi target 9.

Keywords Aichi target 9 · Environmental impacts · Generic impact scoring system (GISS) · Prioritization of alien species · Risk assessment · Socio-economic impacts

Introduction

Human global activities enable an increasing number of species to reach regions outside of their native range, establish self-sustaining populations and spread into natural habitats, a phenomenon known as biological invasion (Elton 1958). Some alien species exert considerable impact on the environment and socio-economy in their new range, leading to large efforts to mitigate these negative effects (Vilà et al. 2008, 2010).

Environmental impacts include not only changes to biodiversity such as a decrease in native species, but also alterations in nutrient or water pools and fluxes leading to changes of whole ecosystem properties (Pyšek et al. 2012; Blackburn et al. 2014; Cameron et al. 2016). The impacts of some alien species go beyond changes to the environment, as they negatively affect production in agriculture, forestry, aquaculture or fisheries. Moreover, they can be of concern for human well-being, for example if they transmit diseases or damage infrastructure (Vilà and Hulme 2017). Therefore, for management to be most effective we need to consider impacts across sectors and taxa. Furthermore, not all alien species cause large impacts, and even among those that do, managers need to prioritize species because there are too many to manage them all (DAISIE 2008).

Lists of the most harmful alien species have been developed to raise awareness amongst the general public, politicians and stakeholders. The most popular amongst these lists are "100 of the world's worst invasive alien species", a global list compiled by the IUCN Invasive Species Specialist Group (ISSG 2017) (hereafter called ISSG-100) and "100 of the most invasive alien species in Europe", composed by the EU DAISIE consortium (DAISIE 2008; Vilà et al. 2008; hereafter called DAISIE-100). These lists are based on expert opinion and cover a variety of taxonomic groups and environments. They were also compiled so as to be representative of a broad range of origins, pathways of introduction, and diversity of impacts. A different type of list also features the worst invaders, but its function is regulatory as it is directly used for management—a so-called "black list" (EU 2016, 2017).

The general value of 100-worst lists is considerable as they provide the argument why certain alien species need management interventions, and showcase a wide variety of potential impacts. The problem of such lists, as well as black lists, is the non-quantitative (and therefore potentially biased) basis for inclusion of species, which makes the applied criteria unclear and relying on expert opinions and preferences (Kumschick et al. 2016). This is largely due to the lack of a generic and reproducible method to compare impacts among taxa, and across regions and habitats. This deficiency might hinder the applicability and usefulness of expert-based lists for science, and in the case of black lists also for management and policy. For prioritization of costly and time-intensive management of harmful alien species, objective and transparent methods of species selection are needed.

Fortunately, in the last decade much progress has been made in this regard and various quantitative and semi-quantitative impact scoring tools have been developed that can be applied across habitats and taxa (e.g. Blackburn et al. 2014; Nentwig et al. 2016; Bacher et al. 2017). Specifically, Nentwig et al. (2016) propose a tool that quantifies both environmental and socioeconomic impacts.

The aim of this study is to produce an as complete as possible list, based on current knowledge, of the worst alien species in Europe using a scoring system applied to animal, plant and fungal taxa, considering all habitats and including environmental and socioeconomic impacts. We present, for the first time, an objective, semi-quantitative, transparent and ranked list to raise awareness of the worst alien species in

Europe and facilitate management and policy of biological invasions on this continent.

Materials and methods

The generic impact scoring system (GISS) is a semi-quantitative tool which relies on published evidence of impact of alien species. Impacts are quantified in 12 categories on a scale from level 0 (no impact detectable) to level 5 (the highest impact possible) with verbal descriptions attached to each level to avoid assessor bias (Nentwig et al. 2016). Several reasons may lead to an impact of 0 (no data available, no impacts known, not detectable, or not applicable) but this does not affect the final result. We discussed this in detail in Kumschick et al. (2015). To perform the GISS assessment, see Table S1.

For the selection of the worst alien species in Europe, we gathered all GISS-assessed taxa from previously published studies including birds (Kumschick and Nentwig 2010; Kumschick et al. 2016; Turbé et al. 2017), mammals (Nentwig et al. 2010), amphibians (Measey et al. 2016), fishes (Van der Veer and Nentwig 2014), terrestrial invertebrates (Vaes-Petignat and Nentwig 2014), spiders (Nentwig 2015), aquatic invertebrates (Laverty et al. 2015), and plants (Rumlerová et al. 2016). We included an additional 52 species assessed by González-Moreno et al. (pers. comm.). The species listed under ISSG-100 (ISSG 2017), DAISIE-100 (DAISIE 2008) and all other species from relevant EU regulations or related publications (EC 2000; ECDC 2012; EU 2010, 2014, 2016) were also assessed for the present study. In total, we compiled impact scores for 486 species alien to Europe (Table S2). As for the EU Regulation on invasive alien species (EU 2014), we only considered species with their entire native distribution outside of Europe, i.e. introduced from other continents, thus excluding species that are native to some region in Europe. We also excluded most pathogens and parasites of humans and livestock because their native range is usually unknown.

To identify the worst of the 486 species assessed we used two complementary independent criteria. We first ranked species according to the total sum of impacts, as obtained from the impact levels for the 12 impact categories (method SUM). The highest impact a species can achieve is a score of 60 (12 impact categories × 5 impact levels). Secondly, we conducted a ranking according to the maximum impact of a species per category (method MAX), similar to the procedure suggested for EICAT classification (Blackburn et al. 2014). Prioritizing the maximum scores is based on the argument that a high impact in one category could be considered as more relevant than multiple impacts with lower scores. This argument is justified by the fact that level 5 impact is defined as “major large-scale impact with high damage and complete destruction, threat to native species including local extinctions, or high economic costs”, thus it is largely irreversible. In contrast, level 4 impact is defined as “major impact with high damage, major changes in ecosystem functions, decrease of native species, or major economic loss”, but such strong impact still can be considered as reversible (Nentwig et al. 2016). Thus, we first ranked all species according to the number of impact categories in which they scored 5. Then we ranked those without a score of 5 in any category according to their frequency of level 4 scores; afterwards the frequency of level 3 scores and so on. For each of the two ranking methods (i.e. SUM and MAX), we selected the 100 highest scoring aliens (or more if ranks were tied). Because both ranking methods have their merits and are complementary, both lists were merged for the final list, i.e. species that occurred on either list or on both were considered for the final list.

Results

From our list of 486 assessed alien species (Table S2), the scores of the total impact of the 100 highest-ranking species (method SUM) ranged from 38 to 16. The total score of 16 was found in 19 species covering positions 88–106, thus making it impossible to select exactly 100 species. According to the second ranking method (method MAX), the 100 highest-ranking species had either at least a score of level 5 in one impact category or a score of level 4 in at least two impact categories. Merging all species from these two lists yielded 149 species. Of these, 75 species were present on both lists, 43 only on the MAX list, and 31 only on the SUM list. Thus, each ranking method missed alien species that the other method considered as high impact. For example, the MAX method did not include hogweed species (*Heracleum* spp.) that scored a total impact sum of 24 but did not score 5 or 4 in any particular impact category (Table 1). Conversely, the SUM method did not include 12 species with scores of 5 in at least one impact category, indicating that their invasion can have devastating consequences through at least one mechanism. Examples include the ruddy duck (*Oxyura jamaicensis*) which hybridise with the native white-headed duck (*Oxyura leucocephala*), and two species of crayfish (*Oronectes* spp.) which transmit the crayfish plague (Table 1). The combination of the two methods therefore leads to the most inclusive list of the worst aliens. Our procedure identified 54 plants (6 non-vascular plants and algae, 48 vascular plants), 49 invertebrates (among them 18 insects, 12 crustaceans, 8 mollusks, and 6 nematodes), 40 vertebrates (18 mammals, 14 fish, 6 birds, 2 amphibians) and 6 fungi as the worst aliens, thus including representatives from all major taxonomic groups. The terrestrial environment is represented by 64% of these species, freshwater by 26%, and marine habitats by 10% (Fig. 1, Table 1).

Discussion

To the best of our knowledge, the here proposed list of 149 alien species in Europe is the most comprehensive, transparent and objective list developed to date that ranks alien species across various taxa according to their overall impacts. However, we are aware that no list will meet all expectations. Some of the species that do not appear on our list, but are included in other expert-based lists are *Ailanthus altissima, Impatiens glandulifera, Diabrotica virgifera, Drosophila suzukii, Leptinotarsa decemlineata, Trachemys scripta elegans* or *Vespa velutina.* These species do not rank highly on our list as currently their total demonstrated impacts are "only" in the range of 11–14 sum of scores and their maximal scores do not exceed a single score of 4. This indicates that we currently lack rigorous scientific proof that impacts of some of these flagship invaders are as serious as perceived by experts. *Impatiens glandulifera* for example, introduced over 100 years ago from India to Europe, was shown to have rather low impacts on species diversity despite its high cover (Hejda et al. 2009). Herbivorous insects such as *Diabrotica virgifera* or *Drosophila suzukii* have a high (score 4) but not devastating impact in their specialized niche but no or only low impacts in other GISS impact categories. However, the impact of a given species may change over time, thus in the future these species might cause higher impacts or additional impacts might be discovered. This also points to the fact that we need more research on the effects of many alien species, and new results might call for updating the list presented here. The same is true for future new arrivals of alien species with high impact: they may also qualify for a list of the worst alien species. Thus both aspects, improved knowledge and more alien species, are likely to generate the need for regular reanalysis, perhaps at 10 years intervals.

The comparison with other 100 worst lists reveals that our selection identifies most of the alien species that were considered as problematic by experts. Our list includes 59 of the DAISIE-100 list (DAISIE 2008). Among the excluded DAISIE-100 species, 19 are marine species, 8 herbivorous insects and 7 plants; for neither of them we found large overall impacts. Four DAISIE-100 species are of European origin, thus cannot be considered here. From the 32 species on the ISSG-100 that fit our selection criteria and occur in Europe, only 6 species (19%) did not make it on our list because their documented impacts were not high enough compared to other aliens in Europe.

The European Union published a list of "alien species of Union concern" initially containing 37 species (EU 2016). Further additions increased the list to 49 species after a complex political process (EU 2017), but more than 100 species were proposed by experts (Roy et al. 2014). Four of these 49 species do not currently occur in Europe, but although they could establish, they cannot be considered for a list of the worst aliens in Europe. Thirteen of the remaining 45 species are not on our list as they were excluded prior to screening or because they scored too low. What is more alerting, however, is that besides the overlapping 32 species found in the EU regulation and on our list, none of the remaining 117 high impact species from our list were included into the EU list of "species of Union concern" and only 16 of our first 49 species with the highest impact made it on the EU list of 49 species. Obviously, it takes more than a high impact for a species to be included on a regulated list. The EU listed species only if it is likely that listing of this species will effectively prevent, minimise or mitigate its impact (EU 2016), and often the most widespread and/or highly impacting species are too costly to be

Table 1 List of the worst alien species for Europe, arranged according to their impact, following the generic impact scoring system (GISS, compare text)

Rank	Total impact sum	Frequency of level 5 impact	Frequency of level 4 impact	Species	Family	Life form	References	Also listed in
1	38	3	4	*Branta canadensis*	Anatidae	Bird	2, 3, 8	D
2	37	3	4	*Rattus norvegicus*	Muridae	Mammal	6	D
3	34	1	4	*Procambarus clarkii*	Cambaridae	Crustacean	1, 8	D, EU*, I
4	32	2	2	*Ondatra zibethicus*	Cricetidae	Mammal	6	D, EU*
5	31	5	1	*Varroa destructor*	Varroidae	Mite	10	EU
6	31	3	0	*Acacia dealbata*	Fabaceae	Plant	1	D
7	31	2	2	*Lantana camara*	Verbenaceae	Plant	7	I
8	31	1	4	*Cervus nippon*	Cervidae	Mammal	6	D
9	30	1	3	*Muntiacus reevesi*	Cervidae	Mammal	6	EU*
10	29	2	4	*Pueraria lobata var. montana*	Fabaceae	Plant	8	EU*
11	29	1	3	*Eichhornia crassipes*	Pontederiaceae	Plant	7	EU*, I
12	28	2	2	*Eriocheir sinensis*	Varunidae	Crustacean	4	D, EU*, I
13	28	2	1	*Robinia pseudoacacia*	Fabaceae	Plant	1	D
14	28	1	3	*Procambarus fallax*	Cambaridae	Crustacean	8	EU*
15	28	0	3	*Acridotheres tristis*	Sturnidae	Bird	2, 3, 8	
16	27	2	2	*Sciurus carolinensis*	Sciuridae	Mammal	6	D, EU*, I
17	27	1	2	*Myocastor coypus*	Echimyidae	Mammal	6	D, EU*, I
18	26	2	1	*Hymenosyphus pseudo-albidus*[a]	Helotiaceae	Fungus	1	
19	25	3	2	*Neovison vison*	Mustelidae	Mammal	6	D
20	24	0	3	*Carassius auratus*	Cyprinidae	Fish	11	
21	24	0	2	*Cortaderia selloana*	Poaceae	Plant	1	D
22	24	0	1	*Heracleum mantegazzianum*	Apiaceae	Plant	1	D, EU*
22	24	0	1	*Heracleum persicum*	Apiaceae	Plant	8	EU*
22	24	0	1	*Heracleum sosnowskyi*	Apiaceae	Plant	8	EU*
23	23	2	1	*Dreissena polymorpha*	Dreissenidae	Mollusk	1, 4	D
24	23	1	3	*Elodea canadensis*	Hydrocharitaceae	Plant	7	D
25	23	0	4	*Procyon lotor*	Procyonidae	Mammal	6	D, EU*
26	23	0	3	*Phytophthora plurivora*	Phytiaceae	Fungus-like	1	
27	22	3	1	*Pheidole megacephala*	Formicidae	Insect	8	
28	22	1	3	*Crassula helmsii*	Crassulaceae	Plant	7	D
29	22	1	2	*Ophiostoma novo-ulmi*	Ophiostomataceae	Fungus	8	D, I
30	22	0	4	*Anoplophora chinensis*	Cerambycidae	Insect	10	D
31	22	0	2	*Ambrosia artemisiifolia*	Asteraceae	Plant	1	D
31	22	0	2	*Axis axis*	Cervidae	Mammal	6	

Table 1 continued

Rank	Total impact sum	Frequency of level 5 impact	Frequency of level 4 impact	Species	Family	Life form	References	Also listed in
31	22	0	2	*Corvus splendens*	Corvidae	Bird	8	EU*
32	22	0	2	*Phytophthora alni*	Phytiaceae	Fungus-like	1	
33	22	0	1	*Parthenium hysterophorus*	Asteraceae	Plant	8	EU*
34	21	2	2	*Oreochromis mossambicus*	Cichlidae	Fish	8	
35	21	1	2	*Seiridium cardinale*	Amphisphaeriaceae	Fungus	8	D
36	21	0	3	*Castor canadensis*	Castoridae	Mammal	6	
37	21	0	2	*Fallopia japonica*	Polygonaceae	Plant	7	D, I
38	21	0	1	*Opuntia ficus-indica*	Cactaceae	Plant	1	D
39	20	1	0	*Saperda candida*	Cerambycidae	Insect	8	
40	20	0	2	*Pomacea canaliculata*	Ampullariidae	Mollusk	1, 8	I
40	20	0	2	*Siganus luridus*	Siganidae	Fish	1	
41	20	0	1	*Linepithema humile*	Formicidae	Insect	1	D, I
42	19	2	1	*Arundo donax*	Poaceae	Plant	7	I
42	19	2	1	*Potamopyrgus antipodarum*	Hydrobiidae	Mollusk	4	
43	19	1	2	*Pacifastacus leniusculus*	Astacidae	Crustacean	4	EU*
44	19	1	0	*Hydrocotyle ranunculoides*	Araliaceae	Plant	7	EU*
45	19	0	4	*Ficopomatus enigmaticus*	Serpulidae	Annelid worm	8	D
45	19	0	4	*Mnemiopsis leidyi*	Bolinopsidae	Comb jelly	1	D, I
45	19	0	4	*Phytophthora cinnamomi*	Phytiaceae	Fungus-like	8	D, I
46	19	0	2	*Ludwigia grandifloria*	Onagraceae	Plant	8	EU*
46	19	0	2	*Ludwigia peploides*	Onagraceae	Plant	8	EU*
47	19	0	0	*Azolla filiculoides*	Salviniaceae	Plant	1	
47	19	0	0	*Lupinus polyphyllus*	Fabaceae	Plant	1	
47	19	0	0	*Rhopilema nomadica*	Rhizostomatidae	Jellyfish	1	D
48	18	2	2	*Aethina tumida*	Nitidulidae	Insect	8	
48	18	2	2	*Oreochromis niloticus*	Cichlidae	Fish	8	
49	18	1	1	*Cherax quadricarinatus*	Parastacidae	Crustacean	8	
50	18	1	0	*Eucalyptus globulus*	Myrtaceae	Plant	7	
51	18	0	3	*Alternanthera philoxeroides*	Amaranthaceae	Plant	8	EU*
52	18	0	2	*Caulerpa racemosa*	Caulerpaceae	Algae	1	D
52	18	0	2	*Lithobates catesbeianus*	Ranidae	Amphibian	1	D, EU*, I
52	18	0	2	*Rapana venosa*	Muricidae	Mollusk	1	D
52	18	0	2	*Siganus rivulatus*	Siganidae	Fish	8	D
53	18	0	1	*Bursaphelenchus xylophilus*	Parasitaphelenchidae	Roundworm	1	D
53	18	0	1	*Sicyos angulatus*	Cucurbitaceae	Plant	1	

Table 1 continued

Rank	Total impact sum	Frequency of level 5 impact	Frequency of level 4 impact	Species	Family	Life form	References	Also listed in
54	18	0	0	*Paralithodes camtschaticus*	Lithodidae	Crustacean	8	D
55	17	2	1	*Oreochromis aureus*	Cichlidae	Fish	8	
56	17	1	0	*Ammotragus lervia*	Bovidae	Mammal	6	
56	17	1	0	*Threskiornis aethiopicus*	Threskiornithidae	Bird	2, 3	D, EU*
57	17	0	3	*Caulerpa taxifolia*	Caulerpaceae	Algae	8	D, I
58	17	0	2	*Anoplophora glabripennis*	Cerambycidae	Insect	10	D, I
58	17	0	2	*Paysandisia archon*	Castniidae	Insect	8	EU
58	17	0	2	*Pomacea maculata*[b]	Ampullariidae	Mollusk	8	
59	17	0	1	*Aedes albopictus*	Culicidae	Insect	1	D, I
59	17	0	1	*Baccharis halimifolia*	Asteraceae	Plant	1	EU*
59	17	0	1	*Harmonia axyridis*	Coccinellidae	Insect	10	D
59	17	0	1	*Prunus serotina*	Rosaceae	Plant	7	D
59	17	0	1	*Pseudorasbora parva*	Cyprinidae	Fish	11	D, EU*
59	17	0	1	*Senecio mikanioides*	Asteraceae	Plant	7	
59	17	0	1	*Solanum elaeagnifolium*	Solanaceae	Plant	1	
59	17	0	1	*Solidago canadensis*	Asteraceae	Plant	7	
60	17	0	0	*Cydalima perspectalis*	Crambidae	Insect	1	
60	17	0	0	*Oncorhynchus mykiss*	Salmonidae	Fish	1	I
61	16	1	2	*Micropterus dolomieu*	Centrarchidae	Fish	8	
62	16	1	1	*Cherax destructor*	Parastacidae	Crustacean	8	
63	16	1	0	*Dikerogammarus villosus*	Gammaridae	Crustacean	1	D
64	16	0	3	*Cacomba caroliniana*	Cacombaceae	Plant	8	EU*
64	16	0	3	*Callosciurus finlaysonii*	Sciuridae	Mammal	6	
65	16	0	2	*Arctotheca calendula*	Asteraceae	Plant	7	
65	16	0	2	*Balanus improvisus*	Balanidae	Crustacean	8	D
65	16	0	2	*Ctenopharyngodon idella*	Cyprinidae	Fish	11	
65	16	0	2	*Eucalyptus camaldulensis*	Myrtaceae	Plant	7	
65	16	0	2	*Odocoileus virginianus*	Cervidae	Mammal	6	
65	16	0	2	*Tradescantia fluminensis*	Commelianaceae	Plant	7	
66	16	0	1	*Frankliniella occidentalis*	Thripidae	Insect	10	D
66	16	0	1	*Nasua nasua*	Procyonidae	Mammal	8	EU*
66	16	0	1	*Nyctereutes procyonoides*	Canidae	Mammal	6	D, EU*
67	16	0	0	*Ambrosia trifida*	Asteraceae	Plant	7	
67	16	0	0	*Eleagnus angustifolia*	Elaeagnaceae	Plant	7	
67	16	0	0	*Pistia stratiotes*	Araceae	Plant	1	
67	16	0	0	*Psittacula krameri*	Psittacidae	Bird	9	D
67	16	0	0	*Tamias sibiricus*	Sciuridae	Mammal	6	D, EU*
68	15	1	1	*Orconectes virilis*	Astacidae	Crustacean	8	EU*
68	15	1	1	*Spartina anglica*	Poaceae	Plant	8	D, I

Table 1 continued

Rank	Total impact sum	Frequency of level 5 impact	Frequency of level 4 impact	Species	Family	Life form	References	Also listed in
69	15	1	0	*Acacia saligna*	Fabaceae	Plant	7	
69	15	1	0	*Panonychus citri*	Tetranychidae	Mite	10	
70	15	0	3	*Carpobrotus acinaciformis*	Aizoaceae	Plant	7	
71	15	0	2	*Cotula coronopifolia*	Asteraceae	Plant	7	
71	15	0	2	*Sphagneticola trilobata*[c]	Asteraceae	Plant	8	
71	15	0	2	*Xenopus laevis*	Pipidae	Amphibian	5	
72	14	1	2	*Carpobrotus edulis*	Aizoaceae	Plant	7	D
73	14	1	1	*Tuta absoluta*	Gelechiidae	Insect	10	
74	14	0	2	*Homarus americanus*	Nephropidae	Crustacean	8	
74	14	0	2	*Marisa cornuarietis*	Ampullariidae	Mollusk	8	
74	14	0	2	*Saurida undosquamis*	Synodontidae	Fish	8	D
75	13	1	1	*Crassostrea gigas*	Ostreidae	Mollusk	4	D
76	13	0	2	*Alexandrium catenella*	Goniodomataceae	Protist	8	D
76	13	0	2	*Ligustrum sinense*	Oleaceae	Plant	8	
76	13	0	2	*Poecilia reticulata*	Poeciliidae	Fish	11	
76	13	0	2	*Rosa rugosa*	Rosaceae	Plant	7	D
76	12	0	3	*Campylopus introflexus*	Dicranaceae	Plant	8	D
77	12	0	3	*Hedychium gardnerianum*	Zingiberaceae	Plant	8	D, I
78	12	0	2	*Ovis orientalis*	Bovidae	Mammal	6	
79	11	1	1	*Acacia longifolia*	Fabaceae	Plant	7	
80	11	0	2	*Buddleja davidii*	Buddlejaceae	Plant	7	
80	11	0	2	*Gambusia holbrooki*	Poeciliidae	Fish	11	
80	11	0	2	*Grapholita molesta*	Tortricidae	Insect	10	
80	11	0	2	*Herpestes javanicus*[d]	Herpestidae	Mammal	6	EU*, I
80	11	0	2	*Liriomyza trifolii*	Agromyzidae	Insect	8	EU
80	11	0	2	*Tilapia zillii*	Cichlidae	Fish	8	
81	10	2	0	*Anguillicola crassus*	Anguillicolidae	Roundworm	4	D
82	10	0	2	*Aedes aegypti*	Culicidae	Insect	8	
82	10	0	2	*Corbicula fluminea*	Corbiculidae	Mollusk	4	D
83	9	1	1	*Ehrharta calycina*	Poaceae	Plant	8	
84	9	0	2	*Anthonomus grandis*	Curculionidae	Insect	8	EU
84	9	0	2	*Euonymus fortunei*	Celestraceae	Plant	8	
85	8	1	0	*Orconectes limosus*	Astacidae	Crustacean	4	EU*
85	8	1	0	*Oxyura jamaicensis*	Anatidae	Bird	2	D, EU*
86	8	0	2	*Bonnemaisonia hamifera*	Bonnemaisoniaceae	Algae	8	D
86	8	0	2	*Globodera pallida*	Heteroderidae	Roundworm	8	EU
86	8	0	2	*Globodera rostochiensis*	Heteroderidae	Roundworm	8	EU
86	8	0	2	*Helicoverpa armigera*	Noctuidae	Insect	8	EU
86	8	0	2	*Meloidogyne chitwoodi*	Meloidogynidae	Roundworm	8	EU
86	8	0	2	*Meloidogyne fallax*	Meloidogynidae	Roundworm	8	EU

Table 1 continued

Rank	Total impact sum	Frequency of level 5 impact	Frequency of level 4 impact	Species	Family	Life form	References	Also listed in
86	8	0	2	*Opogona sacchari*	Tineidae	Insect	8	EU

The overall rank of a species results from the total impact sum (method SUM) and the frequencies of level 5 and level 4 impacts (method MAX), the highest and second highest impact levels for any of the 12 impact categories within the GISS assessment, respectively

References refer to (1) González-Moreno et al. (pers. comm.), (2) Kumschick and Nentwig (2010), (3) Kumschick et al. (2016), (4) Laverty et al. (2015), (5) Measey et al. (2016), (6) Nentwig et al. (2010), (7) Rumlerovà et al. (2016), (8) this study, (9) Turbé et al. (2017), (10) Vaes-Petignat and Nentwig (2014), (11) van der Veer and Nentwig (2014). The listed species are also listed in D = DAISIE (2008); EU = EU (2010, 2014) including EC (2000) and ECDC (2012); EU* refers to species of Union concern (EU 2016, 2017); I = ISSG (2017)

[a] *Hymenosyphus fraxineus*

[b] *Pomacea insularum*

[c] *Wedelia trilobata*

[d] *Herpestes auropunctatus*

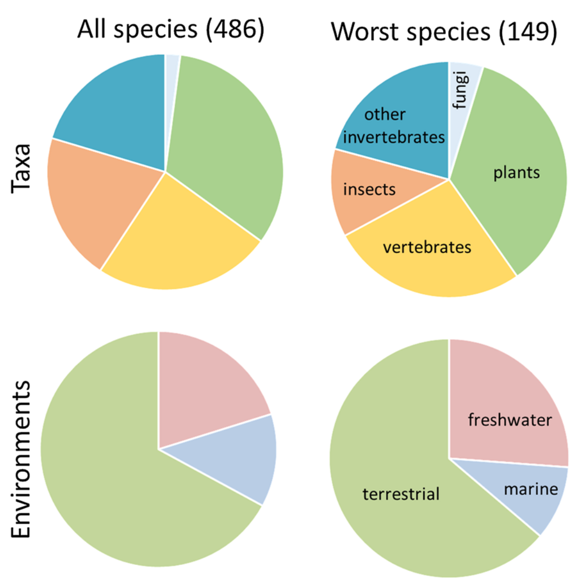

Fig. 1 The comparison of all 486 alien species on the initial list (left column) with the 149 worst species (right column) with respect to five main taxa groups (upper row) and three main environments (lower row) shows that the assessment process did not favor any taxon group or environment

managed effectively. Also economic interests such as with *Acacia*, *Robinia* and *Eucalyptus* species in forestry can prevent the inclusion on such a regulatory list.

The EU is very stringent in species selection and they require the support from their member states to be approved, therefore, such a list can only be seen as lowest common denominator after a long compromise searching process. This could be a reason for the complete lack of marine species on the list of "EU concern", whereas aquatic plants (10 species), crayfish (5 species) and squirrels (4 species) are well represented. In addition, the EU list does not include species which are "regulated elsewhere", such as alien species with impact on agriculture, forestry or human health. All other mentioned 100-lists include such species which aggravates a direct comparison between political and scientific lists.

Our 149 worst species list contains 64 species that do not appear in other worst lists (DAISIE-100, ISSG-100, EU 2017). Examples include *Varroa destructor* (rank 8 on our list), an Asian ectoparasite of the honey bee that has been implicated in the global pollinator crisis (Potts et al. 2010); *Hymenoscyphus pseudoalbidus* (rank 18), the fungus responsible for ash dieback, changes in forest composition and related diversity loss (Gross et al. 2014); *Carassius auratus* (rank 20), the Chinese gold fish, which causes decline of native amphibians (Cats and Ferrer 2003); and the oomycete *Phytophthora plurivora* (rank 26), responsible for the dieback of numerous tree species, among them beech and oak (Schoebel et al. 2014). This indicates that even high-impacting alien species may escape the perception of experts. The selection process behind the list presented here, including screening of large databases of alien species and a semi-quantitative assessment with GISS which considers the published literature, is time-consuming but provides some guarantee that important species are not missed. Therefore, it is justified to recommend that many species from our list should be considered for inclusion on regulatory lists.

Many alien species on our 149 worst list do not yet have an EU wide distribution. For a national strategy, therefore regionalized lists would be very important. However, such subsets require detailed distribution maps and targeted collection of data on impact that are applicable to individual regions. So far, the majority of impact assessments did not follow such an approach because there is simply not enough regionally specific information.

Each of the two complementary approaches (SUM, MAX) identified slightly different sets of alien species with high impacts. The SUM approach favors species with multiple impacts in different categories while the MAX approach favors species with very high impacts in a single category. About half of the species on the final list were identified by only one of these two approaches. Depending on the stakeholders' aim for the prioritization, one or the other might be more appropriate, but both have their merits (Nentwig et al. 2016; Blackburn et al. 2014; Bacher et al. 2017). Thus, we suggest applying either method or their combination depending on the specific needs of the stakeholders.

Our list of the worst aliens in Europe is the first compiled by using a semi-quantitative assessment across taxa and habitats. Such a transparent and reproducible procedure is crucial to ensure the authority of the resulting list. Furthermore, its broad basis of 486 analyzed species makes it less likely that important species are missed. For management purposes, it is increasingly relevant to prioritize alien species. Also politicians have to focus on key species, either for financial or for consensus reasons. In all such regards, an objective list such as the one given here, that is unbiased by expert opinion, taxonomy and environments, can be the basis for evidence based decision making. Such a list is also the ideal tool to fulfill the Aichi biodiversity target 9 that requires prioritization of invasive alien species based on scientific evidence by 2020 (CBD 2017).

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